Reversed optimality and predictive ecology

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SUPPLEMENTARY THEORETICAL SECTION

The food-safety trade-off in a changing environment

When predation danger or food availability changes, it is not immediately clear how the optimal choice under a food-safety trade-off changes. A graphical approach introduced by McNamara & Houston (1994) clarifies matters in this case. It concerns plotting all foraging options, each with its unique food intake rate *H* and predation risk μ, in a state-space of μ against *H* (such as in figure S1). In order to understand how the 'fitness-landscape' behaves in such a state-space, we first need to derive some equations.

Under a food-safety trade-off, an animal should maximize its net energetic benefits of feeding, *H*-*P*, which is its food intake rate *H* [J s^{-1}] minus its predation cost *P* [J s^{-1}]. Multiplying these net energetic benefits with the marginal value of energy $\partial F / \partial e$ [J^{-1}] gives the net rate of change in reproductive value, which we will call $\dot{F}$ [s^{-1}]. Thus (Brown & Kotler 2004; Houston & McNamara 1999):

$$\dot{F} = \partial F / \partial e \, (H - P) \qquad \text{(S1).}$$

Since

$$P = \frac{\mu F}{\partial F / \partial e} \qquad \text{(S2),}$$

eq. S1 can also be written as (Houston & McNamara 1989):

$$\dot{F} = H \, \partial F / \partial e - \mu F \qquad \text{(S3).}$$

In order to plot lines of equal $\dot{F}$ (i.e. 'fitness-landscape') in a μ-*H* state-space we need to rearrange this equation to:

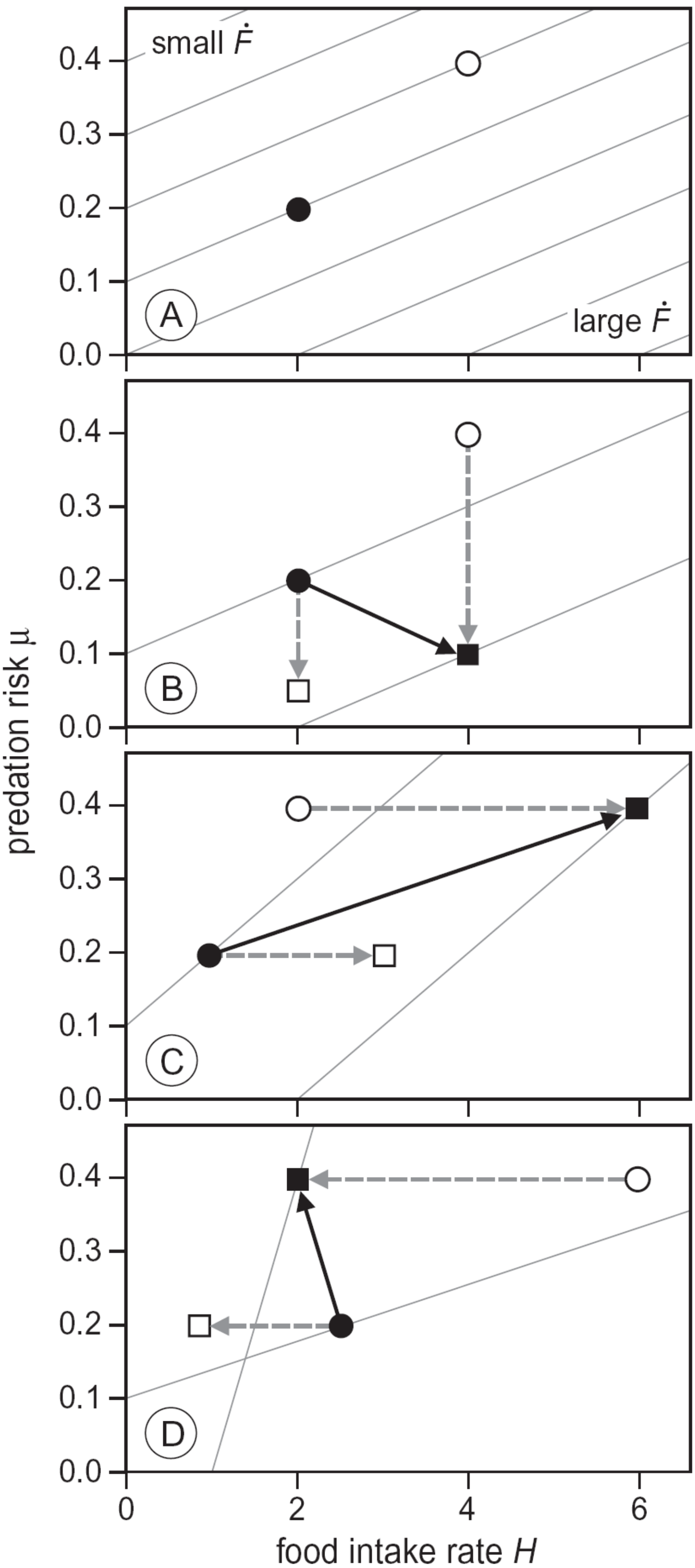
$$\mu = H \frac{\partial F / \partial e}{F} - \frac{\dot{F}}{F} \qquad \text{(S4),}$$

which shows that in a μ-H state-space lines of equal $\dot{F}$ have a slope of $\frac{\partial F / \partial e}{F}$ (called the 'marginal rate of substitution' of predation risk for energy; Brown 1988) and an intercept of $-\frac{\dot{F}}{F}$. Due to the minus-sign in this latter term, the larger the relative rate of change in reproductive value, $\frac{\dot{F}}{F}$, the lower the intercept, i.e. reproductive values increase fastest in the lower right corner of a μ-H state-space (figure S1).

As explained in detail in figure S1, it can now be seen that there are basically three environmental changes (dashed arrows in figures S1*b*-*d*) that each lead to a shift in preference (solid arrows) from the safest to the riskiest option (as we have seen in *M. balthica*). (1) Most trivial is a decline in predation danger (figure S1*b*). Less trivial are (2) an *in*crease in *short*-term food availability (figure S1*c*), and (3) a *de*crease in *long*-term food availability (figure S1*d*). In the latter case, less food reduces an animal's future reproductive value F and likely increases its marginal value of energy $\partial F / \partial e$, leading to steeper slopes in the 'fitness landscape'. Note that in this graph, we have chosen for equal *relative* changes for the two options (rather than equal *absolute* changes) as this mimics the natural situation most. For example, a reduction in predation danger by 75% most likely leads to a 75%-reduction in predation risk in both options.

[Figure caption:]

Figure S1. The food-safety trade-off in a changing environment: three scenarios leading to a shift in preference from the safest to the riskiest option. (*a*) In general, when an animal can choose between feeding at a high rate under a high risk of predation (upper right dot) or feeding at a lower rate under a lower risk of predation (lower left dot), it depends on an animal's future reproductive value *F* and its marginal value of energy $\partial F / \partial e$ which option is optimal. Namely, lines of equal net rate of change in reproductive value (diagonal lines) have a slope of $\frac{\partial F / \partial e}{F}$. Therefore, in this example, $\dot{F}$ is maximized by selecting the safer option (as in all further graphs, the optimal choice is filled and the suboptimal choice is open). (*b*) When predation *danger* declines, an animal should switch from the safest to the riskiest option (which, due to the decline in predation *danger*, still leads to a reduction in predation *risk*). As in all further graphs, circles refer to initial options and squares to final options after the environmental change (given by dashed arrows). The solid arrow gives the shifting optimal choice. (*c*) When food availability increases, but only temporarily (i.e. not leading to change in *F* and/or $\partial F / \partial e$), an animal should also switch from the safest to the riskiest option. (*d*) Also when *long*-term food availability *de*creases should an animal switch from the safest to the riskiest option. This is because an animal's *F* will decline (and its $\partial F / \partial e$ will likely increase) when there is less food available in the long run, leading to an increasing slope in the lines of equal net rate of change in reproductive value.



small $\dot{F}$
large $\dot{F}$
A
B
C
D
0.4
0.3
0.2
0.1
0.0
0
2
4
6
predation risk μ
food intake rate *H*

Figure S1

[References:]

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